

# Adware, Shareware, and Consumer Privacy\*

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## Abstract

Programmers can distribute new software to online users either for a fee as shareware or bundle it with advertising banners and distribute it for free as adware. In this paper we study the programmers' choice between these two modes of distribution in the context of a model that take explicit account of the strategic interaction between programmers who develop software, firms that advertise their products through ad banners, and consumers who buy software and consumer products. Adware allows advertisers to send targeted information to specific consumers and may therefore improve their purchasing decisions. At the same time, adware also raises privacy concerns. We study the effect of programmers' choice between shareware and adware on consumers' welfare through its effect on the beneficial information that consumers receive about consumers products on the one hand and their loss of privacy on the other hand. We also examine the implications of improvements in the technology of ad banners and the desirability of bans on the use of adware.

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# 1 Introduction

In recent years, an increasing number of software providers began to distribute their software online by allowing consumers to download the software from the provider's website. Until the end of the 1990's online software was mainly distributed as shareware: consumers are free to download the software for a trial period but must pay for using the software once the trial period expires. By the end of the 1990's some software providers began to distribute their software as adware which is distributed for free but is supported by advertisers who pay the software provider for displaying ad banners or pop-up ads while the software is being used.<sup>1</sup> In this paper we study the choice of programmers between these two modes of distribution in the context of a model that takes explicit account of the strategic interaction between programmers, firms that sell consumer products and may advertise their products through ad banners, and consumers who buy software and products.

A main premise of our analysis is that the targeted information about consumer products sent to specific adware users through ad banners is potentially beneficial as it may improve their purchasing decisions. This premise is based on the observation that firms are willing to pay programmers considerable amounts for displaying ad banners on the desktops of adware users. A case in point is the Claria Corporation which is one of the pioneers in online behavioral marketing with over 900 advertisers, including 85 of the Fortune 1,000 and an annual revenue of 90.5 million in 2003 and a profit of \$35 million. In our model, consumers differ in their preferences over products but may not know at the outset which firm sells which product. Ad banners allow firms to send targeted ads to consumers that inform them about products that match their tastes. Consequently, firms are willing to pay for ad banners as those raise the likelihood that consumers will purchase their products.

While adware allows advertisers to send potentially useful targeted information to specific consumers, it also raises privacy concerns. Recent surveys show that many consumers are concerned about the misuse of their private information collected online and refrain from buying

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<sup>1</sup>There are several definitions of adware. In this paper we only consider "legitimate" ad-supported software which is installed with the end-user consent. We do not consider "spyware" which is often installed without the end-user consent and tracks and collects personal information without consent (see e.g., Urbach and Kibel (2004)). For a discussion on the histories of shareware and adware, see for example, Knopf (2000) and Stern (2004).

online due to uncertainty regarding the usage of personal data (see e.g., IBM Global Services, 1999).<sup>2</sup> Definitions of privacy vary widely according to context and environment. Posner (1981) discusses several possible definitions, including the “concealment of information,” “peace and quite,” and “freedom and autonomy.” In this paper we consider the second definition, namely privacy as the right for “peace and quite.”<sup>3</sup> This right is a main reason behind the “do-not-call list” that is enforced in the US by the FTC and FCC, and is intended to prevent telemarketers from violating consumers’ privacy at home.<sup>4</sup> We capture the desire of consumers for “peace and quite” by assuming that, in addition to potentially useful information about consumer products, adware users also get a disutility from targeted ads and that this disutility increases with the number of ad banners that are displayed on their desktops.

We begin the paper by considering a model in which a single UK programmer has developed a new software and needs to decide whether to distribute online as an adware or as a shareware. Under the first option, consumers can download the software for free and derive utility from its usage, but in addition, they face a trade off between the beneficial information about consumer products conveyed by ad banners against the disutility from privacy loss. In equilibrium, consumers with large privacy concerns will not adopt the adware while those with relatively small privacy concerns will adopt it. In turn, the number of adopters determines the willingness of firms to pay for ad banners and hence the programmer’s profit from adware. If the programmer

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<sup>2</sup>Interestingly, the IBM study also shows that in the U.S., Germany, and the UK “A minority of consumers ... say they are interested in receiving marketing material. Yet, in far greater numbers, consumers view personalized marketing as a good thing and, in practice, almost half of all consumers in each country have purchased something from a catalog mailed to their home in the past year.” This suggests that there may be a gap between rhetoric and actual behavior.

<sup>3</sup>Our notion of privacy is also consistent with Smith (2000) who defines privacy as “the desire by each of us for physical space where we can be free of interruption, intrusion, embarrassment, or accountability and the attempt to control the time and manner of disclosures of personal information about ourselves.”

<sup>4</sup>In a decision from February, 17, 2004, the U.S. Court of Appeals for the Tenth Circuit held that “the do-not-call registry” targets speech that invades the privacy of the home, a personal sanctuary that enjoys a unique status in our constitutional jurisprudence” (*Mainstream Marketing Services, Inc., TMG Marketing Inc., and American Teleservices Association v. Federal Trade Commission, et al.*, U.S. Court of Appeals for the 10th Circuit, No. 03-1429, and consolidated cases). Likewise, in *Frisby v. Schultz*, 487 U.S. 474, 484 (1988), the Supreme Court of the U.S. held that “One important aspect of residential privacy is protection of the unwilling listener. ... [A] special benefit of the privacy all citizens enjoy within their own walls, which the State may legislate to protect, is an ability to avoid intrusions. Thus, we have repeatedly held that individuals are not required to welcome unwanted speech into their own homes and that the government may protect this freedom.” And, in *FCC v. Pacifica Found.*, 438 U.S. 726, 748 (1978) the Supreme Court of the U.S. held that “[I]n the privacy of the home ... the individuals right to be left alone plainly outweighs the First Amendment rights of an intruder.”

chooses to distribute the software as a shareware he sets a price for the software and sells it to consumers.

We show that in equilibrium, the programmer will distribute his software as an adware provided that its innate quality is relatively low. When the software's innate quality increases above a certain threshold, the programmer will switch to shareware. This pattern is consistent with the experience of several popular software (e.g., Gozilla and GetRight which are the second and the third most popular download managers on download.com with over 17 million and 11 million downloads respectively) that were first distributed as adware, but then, newer and improved versions were distributed as shareware.

Given the fact that adware is still in its infancy, it is expected that in the near future, the technology of context-based advertising will improve. A case in point is Gmail which is a new free webmail service that Google plans to offer. Gmail will place text ads and links to related web pages adjacent to relevant email messages by quickly analyzing their content and determining which ads are most relevant to them.<sup>5</sup> Such improvements have raised concerns about the increasing loss of privacy on the Internet.<sup>6</sup> In our model such improvements affect both consumers' privacy as well as their information on consumers' products. We show that such improvements will induce the programmer to offer adware for a wider set of parameters. Hence, consumers with large privacy concerns may be worse off since in order to obtain the software they would have to receive ad banners which lower their utility. Yet, our analysis shows that in the aggregate, consumers become better off.

Unlike adware, "spyware" (or even "malware") is often installed without the end-user's knowledge and tracks and collects personal information without consent (see e.g., Urbach and Kibel (2004)). The rapid growth of spyware has become a serious problem. Apart from violations of privacy, spyware also causes various technical problems including slow performance of computers, inability to access the Internet, extra icons and pop up ads, Internet or system freezes, and so on.<sup>7</sup> This rapid growth has prompted legislators in the U.S. to consider legislation

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<sup>5</sup>See <http://gmail.google.com/gmail/help/about.html>

<sup>6</sup>For example, a recent article in MSNBC.com Science and Technology, "Privacy advocates target Google mail" <http://msnbc.msn.com/id/4679359/> argues among other things that Gamil "is spooky enough to rankle privacy advocates, who say Google is going too far by poking through individual e-mails."

<sup>7</sup>In a workshop on Spyware held at the FTC in April 2004, Bryson Gordon from McAfee Security, argued that spyware related problems are right now "the single largest issue that we are seeing," and Maureen Cushman from

that would either ban or substantially restrict the use ad-supported software. Utah has already passed such legislation that, among other things, prohibits any party from installing software that monitors computer usage, uses context-based triggering mechanisms, and also prohibits the use of context-based pop-ups that obscure the underlying content. Similar legislation are currently pending in California, the U.S. Senate (Spy Block Act, S.2145) and House of Representatives (Safeguard Against Privacy Invasions Act H.R. 2929), and several other states. Our paper shows that imposing such bans on legitimate ad-supported software may harm consumers by preventing them from receiving useful targeted ads.

We also consider competition in the software market between two programmers: one who provides adware and another who provides shareware. Here we consider the equilibrium in the software market when the adware provider sets the price of ad banners that firms pay when they display ad banners and the shareware provider sets the price of the shareware. We show that our main conclusions from the single programmer case continue to hold even when there is competition in the software market.

Our paper contributes among other things to the small but growing literature on the economics of privacy. Several papers in this literature have identified the loss of privacy with the disclosure of information on the consumers' preferences (Acquisti and Varian, 2004; Calzolari and Pavan, 2004; Dodds 2003; Taylor 2002, 2004; and Wathieu, 2002). Such information allows firms to use personalized prices that hurt consumers by extracting their consumers' surplus. But as Varian (1996) points out, when firms learn information about consumers' preferences, they can also offer them products that better meet their needs and thereby lower their search costs. Hence, disclosure of information on consumers' preferences involves a tradeoff between a reduction of search costs and extraction of consumers' surplus. A different approach to consumers' loss of privacy is taken by Hann et al (2003), who consider a model in which some consumers are privacy guardians and are not interested in buying products. They then consider a game in which firms invest resources in identifying potential consumers (though cannot tell whether they are privacy guardians or not) while privacy guardians invest resources in trying to avoid

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Dell argued that spyware become "a huge technical support issue for us," and that "Spyware related technical support calls have been as high as 12 percent of all technical support requests to the Dell technical support queue." See <http://www.ftc.gov/bcp/workshops/spyware/transcript.pdf>

solicitations by firms. They show that competition between firms raises both types of investments (which are socially excessive) and hence raises the cost of privacy protection.<sup>8</sup> Hann et al. (2002) empirically examine individuals' tradeoffs between the benefits and costs of providing personal information to websites. They find that the benefits in terms of monetary reward and future convenience significantly affect individuals preferences over websites with differing privacy policies. Among U.S. subjects, protection against errors, improper access, and secondary use of personal information is worth \$30.49 – \$44.62.

The rest of the paper is organized as follows: Section 2 presents the model. In Section 3 we solve for the equilibrium when there is a single programmer who needs to choose whether to distribute his software online as an adware or as a shareware. Section 4 examines the effect of a technological improvement in the ad banners technology on the equilibrium and also considers the policy implications of the model. Section 5 considers the equilibrium when there is competition between adware and shareware. We conclude in Section 6.

## 2 The model

There are three types of agents in our model: a programmer, a continuum of consumers, and  $n \geq 2$  firms that sell consumer products. The programmer develops a software and distributes it to consumers online. The software is either sold to consumers as a shareware or is bundled with ad banners and is distributed to consumers for free. In the latter case, the programmer collects fees from firms that use ad banners that are displayed on the desktops of adware users to advertise their products.

### 2.1 The timing of the model

The model evolves in three stages. In the first stage, the programmer chooses whether to distribute his software online as a shareware or as an adware. Under the first option, the programmer sets a price for the shareware that consumers need to pay for using it once the

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<sup>8</sup>McAndrews and Morgan study a related model in which phone service users can buy caller ID service in order to block unwanted calls (e.g., from telemarketers) while callers can buy ID blocking which overrides caller ID. They show that without both a well established right to identify callers, and well functioning markets for the services, inefficient allocations emerge.

trial period expires. Under the second option, the programmer sets a per-viewer advertising fee that firms must pay in order to display ad banners on the desktops of adware users. Then, in the second stage, each consumer decides whether or not to get the software. In the third stage which is reached only if the programmer chooses to distribute his software as an adware, the  $n$  firms choose how many ad banners to display. Finally, consumers buy products and all payoffs are realized.

## 2.2 Consumers

There is a continuum of potential consumers with a total mass of one. Each consumer is interested in buying one software and one out of  $n$  consumer products, each of which is produced by a different firm. Consumers belong to  $n$  different and equal sized groups: consumers who belong to group  $i$  get a utility  $s$  if they buy product  $i$  and  $s - t$  if they buy any other product, where  $s \equiv v - p$  is the difference between the gross utility of buying the “right” product,  $v$ , and the product’s price,  $p$ . For simplicity we assume that  $p$  is the same for all products and treat it as an exogenous parameter. Consumers, however, do not necessarily know of all firms at the outset and can buy from a given firm only if they know about it. Specifically, a consumer who belongs to group  $i$  learns about product  $i$  only with probability  $\varphi$ . With probability  $1 - \varphi$ , the consumer ends up buying some other product. The expected utility of a consumer who chooses not to buy software at all is therefore given by

$$\bar{U} = \varphi s + (1 - \varphi)(s - t). \tag{1}$$

**Shareware users:** Using  $q$  to denote the shareware’s innate quality and  $p^s$  its price, a shareware user gets a net utility  $q - p^s$  from buying a shareware. Hence, the expected utility of a shareware user who belongs to group  $i$  is

$$U^s = q - p^s + \bar{U}. \tag{2}$$

To ensure that we obtain an interior solution for our model, we make the following assumption:

**Assumption 1:**  $q \leq (1 - \varphi) t$ .

Assumption 1 implies that the direct utility from using the software,  $q$ , does not exceed the utility loss due to choosing the “wrong” consumer product. This assumption will ensure that in equilibrium, firms will agree to pay for ad banners.

**Adware users:** If a consumer gets an adware, then in addition to the software he is interested in, he also gets a software that tracks his behavior and enables the programmer to identify his preferences. In our context, that means that the programmer can send adware users in group  $i$  targeted ads that inform them about firm  $i$ .

Let  $k_i$  be the number of impressions that firm  $i$  pays for (i.e., the number of times that firm  $i$ 's ad banners are displayed on the adware user's desktop) and let  $m \in [0, 1]$  be the probability that an ad captures the user's attention. The parameter  $m$  captures the effectiveness of ad banners in informing adware users of products they need. Assuming that the probability of noticing each impression is independent across impressions, the probability that a consumer in group  $i$  notices at least one of the  $k_i$  impressions is

$$\mu_i = 1 - (1 - m)^{k_i}. \quad (3)$$

With probability  $1 - \mu_i = (1 - m)^{k_i}$ , the consumer ignores all  $k_i$  impressions. The function  $\mu_i$  represents the intensity of online advertising.

In what follows it will be easier to express the model in terms of  $\mu_i$  instead of  $k_i$ . To this end, note from equation (3) that

$$k_i = z \ln(1 - \mu_i), \quad z \equiv \frac{1}{\ln(1 - m)}, \quad (4)$$

where  $z < 0$ . Equation (4) represents the number of impressions that firm  $i$  needs to send in order to ensure that its product is noticed by adware users in group  $i$  with probability  $\mu_i$ . Since  $\ln(1 - \mu_i) < 0$ ,  $k_i$  decreases with  $z$ , implying that as  $z$  increases towards 0, the ad banners technology improves, fewer impressions are needed to attract the same level of attention from consumers. Hence,  $z$  which increases with  $m$ , serves as a measure of how effective ad banners are in attracting the attention of adware users.

Apart from ad banners, adware users in group  $i$  also learn about product  $i$  with probability  $\varphi$  just like shareware users. Assuming that the probability of learning about products from an adware is independent of the probability of learning about it from other sources, the probability that an adware user in group  $i$  buys product  $i$  is  $\mu_i + (1 - \mu_i)\varphi$  (the probability that he learns about product  $i$  from the adware plus the probability that he does not learn about it from the adware but does learn about it from other sources), while the probability that he buys product  $j \neq i$  is  $(1 - \mu_i)(1 - \varphi)$ . We assume that if the consumer does not learn about product  $i$  he learns about one of the  $n - 1$  “wrong” products with probability  $\frac{1}{n-1}$ .

While ad banners provide adware users with potentially useful information about consumer products, they also violate their privacy by intruding on their right “to be left alone.” We assume that the resulting disutility that adware users bear is directly related to the number of impressions that are displayed on their desktops and is given by  $\beta k_i$ , where  $\beta$  is uniformly distributed in the population on the support  $[0, B]$ . That is, consumers vary with respect to the extent of their disutility from privacy loss.

Assuming that the innate quality of the adware is also  $q$  and using equation (4), the expected utility of an adware user in group  $i$  is given by

$$\begin{aligned} U_i^a(\beta) &= q - \beta z \ln(1 - \mu_i) + (\mu_i + (1 - \mu_i)\varphi) s + (1 - \mu_i)(1 - \varphi)(s - t) \\ &= q - \beta z \ln(1 - \mu_i) + \mu_i(1 - \varphi)t + \bar{U}. \end{aligned} \quad (5)$$

The third term on the right hand side of equation (5) represents the added information that an adware user gets about consumer products which increases his chance to find the “right” product. The second term is the disutility from lost privacy. This term decreases with  $z$  since an improvement in the ad banners’ technology allows firms to send adware users fewer ads in order to get the same level of attention from them. Hence, the privacy of adware users is violated to a lesser extent.

## 2.3 Firms

Firms’ decisions matter in our model only when the programmer offers an adware. Otherwise, each consumer (whether he owns a shareware or not) either learns about the “right” product

with probability  $\varphi$  or else picks one of the  $n - 1$  “Wrong” products at random. By symmetry then, each firm serves a mass  $\frac{1}{n}$  of consumers, each of whom is interested in buying one unit.

Now, suppose that the programmer offers an adware and suppose that a fraction  $\alpha$  of all consumers adopt it. The remaining consumers do not adopt the adware; as in the shareware case, each firm ends up serving a fraction  $\frac{1}{n}$  of these consumers. Hence, each firm  $i$  faces a mass of  $\frac{1-\alpha}{n}$  of consumers who do not own any software.

Next, we turn to the demand for firm  $i$ 's product among adware users. The total mass of adware users is  $\alpha$ , of which  $\frac{\alpha}{n}$  are in group  $i$ . The probability that adware users in group  $i$  buy from firm  $i$  is  $\mu_i + (1 - \mu_i)\varphi$  while the probability that adware users in group  $j \neq i$  buy from firm  $i$  is  $\frac{(1-\mu_j)(1-\varphi)}{n-1}$  (the probability they fail to learn about product  $j$  times the probability they learn about product  $i$  which is one of the  $n - 1$  “wrong” products). By the law of large numbers, firm  $i$  serves a total of  $\frac{\alpha}{n} \left[ \mu_i + (1 - \mu_i)\varphi + \sum_{j \neq i} \frac{(1-\mu_j)(1-\varphi)}{n-1} \right]$  adware users.

The expected demand that firm  $i$  is facing, given the probability that the ad banners of the  $n$  firms are noticed,  $\mu_1, \dots, \mu_n$ , is:

$$Q_i(\mu_1, \dots, \mu_n) = (1 - \alpha) \frac{1}{n} + \frac{\alpha}{n} \left( \mu_i + (1 - \mu_i)\varphi + \sum_{j \neq i} \frac{(1 - \mu_j)(1 - \varphi)}{n - 1} \right). \quad (6)$$

Assuming that the profit per unit of consumer product is  $\pi \equiv p - c$ , where  $p$  is the price and  $c$  is the (constant) marginal cost, using  $r$  to denote the per-impression per-user price that firms pay adware programmers, and using equation (4), the expected profit of firm  $i$  is

$$\Pi_i(\mu_1, \dots, \mu_n) = Q_i(\mu_1, \dots, \mu_n)\pi - \frac{\alpha}{n} r z \ln(1 - \mu_i). \quad (7)$$

## 2.4 Programmers

For simplicity we begin the model at the point in time after the programmer has already successfully developed his software. Hence, the development costs are already sunk at this point and the programmer's problem is how to distribute the software online. If the programmer chooses to distribute it as a shareware, then given equations (1) and (2), it is clearly optimal to set a price,  $p^s = q$ , for the shareware. The programmer's profit in this case is  $q$ .

If the programmer chooses to distribute the software as an adware then he allows users

to download it for free but then collects money from firms that advertise their products through ad banners. The programmer then sets a price  $r$  for each ad that reaches each consumer and lets firms choose how many for ads to display. The programmer's profit in this case is  $r \sum_{i=1}^n k_i$ , or using equation (4),

$$rz \sum_{i=1}^n \frac{\alpha}{n} \ln(1 - \mu_i).$$

The programmer will then choose  $r$  to maximize his profit from selling ad banners to firms. In the first stage of the game, the programmer will compare the resulting profit from selling adware to the profit from selling shareware,  $q$ , and depending on which is larger will decide how to distribute his software.

### 3 Equilibrium

In this section we solve for the subgame perfect equilibrium in our three-stage model. The equilibrium in the shareware subgame is simple: the programmer sets the price of shareware equal to  $q$  and all consumers buy the software. Consequently, the programmer's profit is  $q$ . Hence we only need to solve stages 2 and 3 in the adware subgame. In order to solve stage 1 of the game, we will then compare the programmer's profits from shareware and adware to determine which mode of the distribution the programmer will choose.

#### 3.1 Stage 3: the choice of targeted ads

We begin with the third stage in which, assuming that the programmer chooses to distribute his software as an adware, each firm  $i$  chooses  $\mu_i$ . The first order condition for  $\mu_i$  is:

$$\frac{\partial \Pi_i(\mu_1, \dots, \mu_n)}{\partial \mu_i} = \frac{\alpha}{n} (1 - \varphi) \pi + \frac{\alpha}{n} rz \frac{1}{1 - \mu_i} = 0.$$

The first term in the derivative is the marginal benefit from ad banners: without ad banners, firm  $i$  cannot capture the attention of the  $1 - \varphi$  adware users in group  $i$  who are not aware of its product from other sources. The associated loss of revenue per each such user is  $\pi$ . The second

term is the marginal cost of ad banners (since  $z < 0$  this term is negative).

Solving the first order condition for  $\mu_i$ , reveals that in equilibrium,

$$\mu_i = \hat{\mu}(r) \equiv 1 + \frac{rz}{(1-\varphi)\pi}, \quad i = 1, 2, \dots, n. \quad (8)$$

Assumption 1 ensures that in stage 1 of the model, the programmer will set  $r$  such that  $\hat{\mu}(r) \geq 0$ . If Assumption 1 fails, firms will prefer not to pay for any ad banners. The function  $\hat{\mu}(r)$  is the demand function of each of the  $n$  firms for ad banners given the price per-impression per-user,  $r$ , that the programmer sets at the first stage of the game. Recalling that  $z < 0$ , equation (8) shows that  $\hat{\mu}(r)$  is a linearly decreasing function of  $r$ .

Equation (8) shows that  $\hat{\mu}(r)$  is increasing with  $\pi$  and  $z$  but is decreasing with  $\varphi$ . Intuitively, firms demand more ad banners when the market is more profitable ( $\pi$  is larger) and when ad banners are more effective in attracting consumers' attention ( $z$  increases towards 0), but demand fewer ad banners when adware users are more likely to know about the "right" products anyway ( $\varphi$  is larger). It is interesting to note that each firm's demand for ad banners is independent of  $\alpha$  which is the fraction of consumer who choose to buy adware. The reason for this is that firms pay per-viewer fees to the programmer and hence if there is a smaller number of adware users, the firms payments to the programmer decrease proportionally.

### 3.2 Stage 2: consumer's demand for adware

When the programmer chooses to distribute the software as an adware, each consumer needs to decide whether or not to adopt it. Substituting for  $\hat{\mu}(r)$  from equation (8) into equation (5) and simplifying, the difference between the utility from having an adware and not having it is

$$U^a(\beta) - \bar{U} = q - \beta z \ln(1 - \hat{\mu}(r)) + \hat{\mu}(r)(1 - \varphi)t. \quad (9)$$

That is, relative to a non user, an adware user gets a utility  $q$  from using the software but also bears a disutility  $\beta z \ln(1 - \hat{\mu}(r))$  from privacy loss. And, due to targeted ads, the adware user gets an additional utility  $\hat{\mu}(r)(1 - \varphi)t$  from buying the "right" product when absent adware he will buy one of the "wrong" products. The probability of this event is  $\hat{\mu}(r)(1 - \varphi)$ .

Consumers will adopt the adware if and only if  $U^a(\beta) - \bar{U} \geq 0$ . Since  $U^a(\beta) - \bar{U}$  is decreasing with  $\beta$ , the equation  $U^a(\beta) = \bar{U}$  defines a unique value of  $\beta$ , denoted  $\hat{\beta}(q, \hat{\mu}(r))$ , below which the consumer will get an adware. Using equation (9),

$$\hat{\beta}(q, \hat{\mu}(r)) = \frac{q + \hat{\mu}(r)(1 - \varphi)t}{z \ln(1 - \hat{\mu}(r))}. \quad (10)$$

Since  $\beta$  is uniformly distributed in the population on the interval  $[0, B]$ , the fraction of consumers who choose to get an adware,  $\alpha$ , is

$$\alpha = \hat{\alpha}(q, r) \equiv \min \left\{ \frac{\hat{\beta}(q, \hat{\mu}(r))}{B}, 1 \right\}. \quad (11)$$

Equation (11) shows that the fraction of adware adopters is increasing with the benefits from having the adware,  $q + \hat{\mu}(r)(1 - \varphi)t$ , and decreasing with the number of impressions that each adware user faces,  $z \ln(1 - \hat{\mu}(r))$ .

The aggregate demand of firms for ad banners is

$$Q(q, r) = \hat{\alpha}(q, r) z \ln(1 - \hat{\mu}(r)),$$

where  $\hat{\alpha}(q, r)$  is the mass of adware users and  $z \ln(1 - \hat{\mu}(r))$  is the equilibrium number of impressions that each firm chooses to send each adware user. Using equations (10) and (11),

$$Q(q, r) = \begin{cases} \frac{q + \hat{\mu}(r)(1 - \varphi)t}{B}, & \frac{\hat{\beta}(q, \hat{\mu}(r))}{B} \leq 1, \\ z \ln(1 - \hat{\mu}(r)), & \frac{\hat{\beta}(q, \hat{\mu}(r))}{B} > 1. \end{cases} \quad (12)$$

The expression in the first line of (12) is the aggregate demand for ad banners when at least some consumers do not adopt the adware (i.e.,  $\hat{\alpha}(q, r) < 1$ ). The expression in the second line is the aggregate demand for ad banners when all consumers adopt the adware (i.e.,  $\hat{\alpha}(q, r) = 1$ ). Notice that since  $\hat{\mu}(r)$  is a decreasing function of  $r$ , the aggregate demand of firms for ad banners is a downward sloping function of the ad banners' price. Intuitively, an increase in  $r$  creates three effects. First, each firm chooses to pay for fewer ad banners per adware user (i.e.,  $z \ln(1 - \hat{\mu}(r))$ )

is smaller). Second, the decrease in the number of ad banners lowers the privacy loss of adware users and therefore tends to boost their number (the denominator in  $\widehat{\beta}(q, \widehat{\mu}(r))$  falls). Third, the decrease in the number of ad banners means that adware users obtain less information about consumer products and hence are less inclined to adopt the adware (the numerator in  $\widehat{\beta}(q, \widehat{\mu}(r))$  falls). In our formulation, the first and second effects just cancel each other out when  $\widehat{\alpha}(q, r) < 1$ . Given that an increase in  $r$  leads to fewer adware users, the aggregate demand for ad banners, which is proportional to the number of adware users, falls.

When  $\widehat{\alpha}(q, r) = 1$ , all consumers already have an adware so only the first effect is at work. Hence, in this case an increase in  $r$  lowers the aggregate demand for ad banners by making it a more costly means of advertising from the viewpoint of firms.

### 3.3 Stage 1: the programmer's problem

In the first stage of the game, the programmer needs to choose whether to distribute his software online as a shareware or as an adware. To determine his choice, we need to compare the programmer's profit under each alternative. In the shareware case, the programmer sets the price of the shareware equal to  $q$ , all consumers buy and the programmer's profit is  $q$ . To determine the programmer's profit from adware, we first need to determine the profit maximizing per-impression price,  $r$ . To this end, notice that given the aggregate demand for ad banners, the programmer's profit from adware is

$$O^a(q, r) = rQ(q, r), \tag{13}$$

where  $Q(q, r)$  is given by equation (12). Noting from equation (12) that  $Q(q, r)$  is increasing with  $\widehat{\mu}(r)$  and recalling from equation (8) that  $\widehat{\mu}(r)$  is decreasing with  $r$ , it follows that  $O^a(r)$  is strictly concave in  $r$  (both when  $B$  is small and when  $B$  is large). Hence, the optimal value of  $r$  is uniquely defined by the equation  $\frac{dO^a(r)}{dr} = 0$ . Solving this equation, the profit maximizing

value of  $r$  is

$$r^* = \begin{cases} -\frac{(q+(1-\varphi)t)\pi}{2zt}, & B \geq \bar{B}, \\ -\frac{(1-\varphi)\pi}{ze}, & B < \bar{B}. \end{cases} \quad (14)$$

where

$$\bar{B} \equiv \hat{\beta}(q, \hat{\mu}(r^*)) = \frac{q + (1 - \varphi)t}{2z \ln\left(\frac{q+(1-\varphi)t}{2(1-\varphi)t}\right)}, \quad (15)$$

is the highest consumer type who still adopts an adware.

Note that  $r^*$  in the first line of equation (14) exceeds  $r^*$  in the second line of equation (14). Intuitively, when  $B$  is large, some consumers do not adopt the adware. As we saw earlier, an increase in  $r$  lowers the number adopters further and hence lowers the aggregate demand for ad banners. The programmer must take this negative effect of  $r$  into account and hence sets a lower  $r$  than in the case where all consumers adopt the adware.

When  $B < \bar{B}$ , all consumers get an adware. Substituting for  $r^*$  from the first line of equation (14) into equation (8), the equilibrium probability that a consumer in group  $i$  notices at least one of firm  $i$ 's impressions is

$$\mu^* \equiv \hat{\mu}(r^*) = \begin{cases} \frac{(1-\varphi)t-q}{2(1-\varphi)t}, & B \geq \bar{B}, \\ 1 - \frac{1}{e}, & B < \bar{B}, \end{cases}$$

Clearly,  $\mu^* < 1$ . Assumption 1 ensures that  $\mu^* \geq 0$ .

When  $B < \bar{B}$ , all consumers get an adware. On the other hand, when  $B \geq \bar{B}$ , the fraction of consumers who get an adware is

$$\hat{\alpha}(q, r^*) = \frac{\bar{B}}{B}.$$

By Assumption 1 and since  $z < 0$ ,  $\hat{\alpha}(q, r^*) > 0$ . Since  $B \geq \bar{B}$ ,  $\hat{\alpha}(q, r^*) \leq 1$ .

Given  $r^*$ , the programmer's profit from adware is

$$O^a(q, r^*) = \begin{cases} -\frac{(q+(1-\varphi)t)^2\pi}{4ztB}, & B \geq \bar{B}, \\ \frac{(1-\varphi)\pi}{e}, & B < \bar{B}. \end{cases} \quad (16)$$

Notice that the expression in the second line of equation (16) exceeds the expression in the first line of equation (16): the programmer is clearly better off when the support of the disutility parameter,  $\beta$ , is small because then, in equilibrium, all consumers adopt the adware and hence the demand for ad banners is maximal.<sup>9</sup>

When  $B < \bar{B}$  (the support of the distribution of  $\beta$  is “narrow”),  $O^a(q, r^*)$  is a linearly increasing function of the probability that the consumers will pick a “wrong” product,  $1 - \varphi$ , and the profit per-unit of consumer product,  $\pi$ , but is independent of the software's quality  $q$ . Intuitively, firms value ad banners more when  $1 - \varphi$  and  $\pi$  are large and this enables the programmer to charge high per-viewer fees for ad banners. And, since all consumers adopt the software anyway, the innate quality of the software is immaterial.

When  $B \geq \bar{B}$  (the support of the distribution of  $\beta$  is “wide”), equation (16) shows that  $O^a(q, r^*)$  is increasing with the software's quality  $q$ , with the probability that consumers will pick a “wrong” product,  $1 - \varphi$ , with the profit per-unit of consumer product,  $\pi$ , and with the effectiveness of ad banners,  $z$ . Intuitively, an increase in  $q$  and  $1 - \varphi$  make adware more attractive so more consumers adopt it. Consequently, firms are willing to pay more money for ad banners as those become more effective means of advertising. Likewise, an increase in  $\pi$  implies that firms are more eager to advertise. When  $z$  increases, firms need to send fewer ad banners to get consumers' attention. This boosts the demand for ad banners and hence the programmer's profit.

In what follows, we shall restrict attention to the (more interesting) case where  $B$  is relatively large by making the following assumption:

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<sup>9</sup>To see that the expression in the second line of equation (16) is larger than the expression in the first line of equation (16), note that  $-\frac{(q+(1-\varphi)t)^2\pi}{4ztB} \leq -\frac{(q+(1-\varphi)t)^2\pi}{4zt\bar{B}} = -\frac{(q+(1-\varphi)t)\pi}{2t} \ln\left(\frac{q+(1-\varphi)t}{2(1-\varphi)t}\right)$ . The last expression is decreasing with  $q$  and hence is largest when  $q = 0$ . Its value at  $q = 0$ , is  $-\frac{(1-\varphi)\pi}{2} \ln\left(\frac{1}{2}\right) < \frac{(1-\varphi)\pi}{e}$ . Hence,  $-\frac{(q+(1-\varphi)t)^2\pi}{4ztB} < \frac{(1-\varphi)\pi}{e}$  for all  $q$ .

**Assumption 2:**  $B \geq \bar{B}$ .

Having found the profit from adware, we now turn to the programmer's choice between adware and shareware. To this end we need to compare the profit from adware,  $O^a(r^*)$ , with the profit from shareware,  $q$ .

**Proposition 1:** *The solution to the programmer's problem is as follows:*

- (i) If  $B < -\frac{(1-\varphi)\pi}{z}$ , the programmer will offer adware for all values of  $q$ .
- (ii) If  $B \geq -\frac{(1-\varphi)\pi}{z}$ , the programmer will offer adware if  $q \leq q_1$  and will offer shareware if  $q > q_1$ , where

$$q_1 \equiv \frac{t \left( 1 + \frac{(1-\varphi)\pi}{2zB} - \sqrt{1 + \frac{(1-\varphi)\pi}{zB}} \right)}{-\frac{\pi}{2zB}}.$$

**Proof:** Suppose that  $B < -\frac{(1-\varphi)\pi}{z}$  and let

$$\Delta(q) \equiv O^a(q, r^*) - q = -\frac{(q + (1-\varphi)t)^2 \pi}{4ztB} - q.$$

Note that  $\Delta''(q) = -\frac{\pi}{2ztB} > 0$  so that  $\Delta(q)$  has a unique minimum,  $q_{\min}$ . Evaluated at  $q_{\min}$ ,

$$\Delta(q_{\min}) = \frac{ztB}{\pi} + (1-\varphi)t.$$

Since  $z < 0$ , it follows that  $\Delta(q_{\min}) > 0$  whenever  $B < -\frac{(1-\varphi)\pi}{z}$ . Hence when  $B < -\frac{(1-\varphi)\pi}{z}$ ,  $O^a(r^*) > q$  for all  $q$ .

Next, suppose that  $B \geq -\frac{(1-\varphi)\pi}{z}$ . Then, the equation  $O^a(r^*) = q$  yields two solutions:

$$q_1 \equiv \frac{t \left( 1 + \frac{(1-\varphi)\pi}{2zB} - \sqrt{1 + \frac{(1-\varphi)\pi}{zB}} \right)}{-\frac{\pi}{2zB}}, \quad q_2 \equiv \frac{t \left( 1 + \frac{(1-\varphi)\pi}{2zB} + \sqrt{1 + \frac{(1-\varphi)\pi}{zB}} \right)}{-\frac{\pi}{2zB}},$$

where  $O^a(r^*) > q$  if  $q < q_1$  or  $q > q_2$ , and  $O^a(r^*) < q$  if  $q_1 \leq q \leq q_2$ . However, by Assumption

1,  $q \leq (1 - \varphi)t$ . Comparing  $q_2$  with  $(1 - \varphi)t$  reveals that

$$q_2 - (1 - \varphi)t = \frac{t \left( 1 + \frac{(1-\varphi)\pi}{zB} + \sqrt{1 + \frac{(1-\varphi)\pi}{zB}} \right)}{-\frac{\pi}{2zB}} \geq 0,$$

where the inequality follows because the assumption that  $B \geq -\frac{(1-\varphi)\pi}{z}$  implies that  $1 + \frac{(1-\varphi)\pi}{zB} \geq 0$ . Likewise, comparing  $q_1$  with  $(1 - \varphi)t$  reveals that

$$q_1 - (1 - \varphi)t = \frac{t \left( 1 + \frac{\pi(1-\varphi)}{zB} - \sqrt{1 + \frac{\pi(1-\varphi)}{zB}} \right)}{-\frac{\pi}{2zB}}.$$

Since  $z < 0$  and since  $B \geq -\frac{(1-\varphi)\pi}{z}$ ,  $0 \leq 1 + \frac{(1-\varphi)\pi}{zB} < 1$ ; hence,  $1 + \frac{(1-\varphi)\pi}{zB} \leq \sqrt{1 + \frac{(1-\varphi)\pi}{zB}}$ , implying that  $q_1 \leq (1 - \varphi)t$ . ■

Proposition 1 is illustrated in Figure 1. When  $q$  is low, shareware users derive little benefit from the software and hence are not willing to pay much for it. Hence, the programmer's profit from shareware is small. On the other hand,  $O^a(0, r^*) > 0$ , implying that the programmer's profit from adware is positive even when  $q = 0$ . Hence, for small values of  $q$ , the programmer prefers to distribute his software as an adware. Intuitively, the programmer's profit from adware comes from firms who advertise their products through ad banners. Obviously, firms will pay for ad banners only if at least some consumers adopt the adware. The question then is whether consumers will or will not adopt the adware when  $q$  is small. To address this question, recall that the benefit to adware users comes both from the software they use as well as from the information about consumer products that they get from ad banners. When  $q = 0$ , adware users do not benefit from the software itself, but since they do not pay for it either, they may still adopt it provided that the benefit from ad banners exceeds the associated disutility from privacy loss. As equation (8) shows, the intensity of advertising per viewer is independent of the mass of adware users. Hence, adware users get useful information about consumers' products even when  $q = 0$ . Although adware users also bear a disutility from privacy loss, equations (10) and (11) reveal that for users with relatively small values of  $\beta$ , this disutility is small relative to the benefits. Consequently, the programmer can make money from adware even when  $q = 0$ .

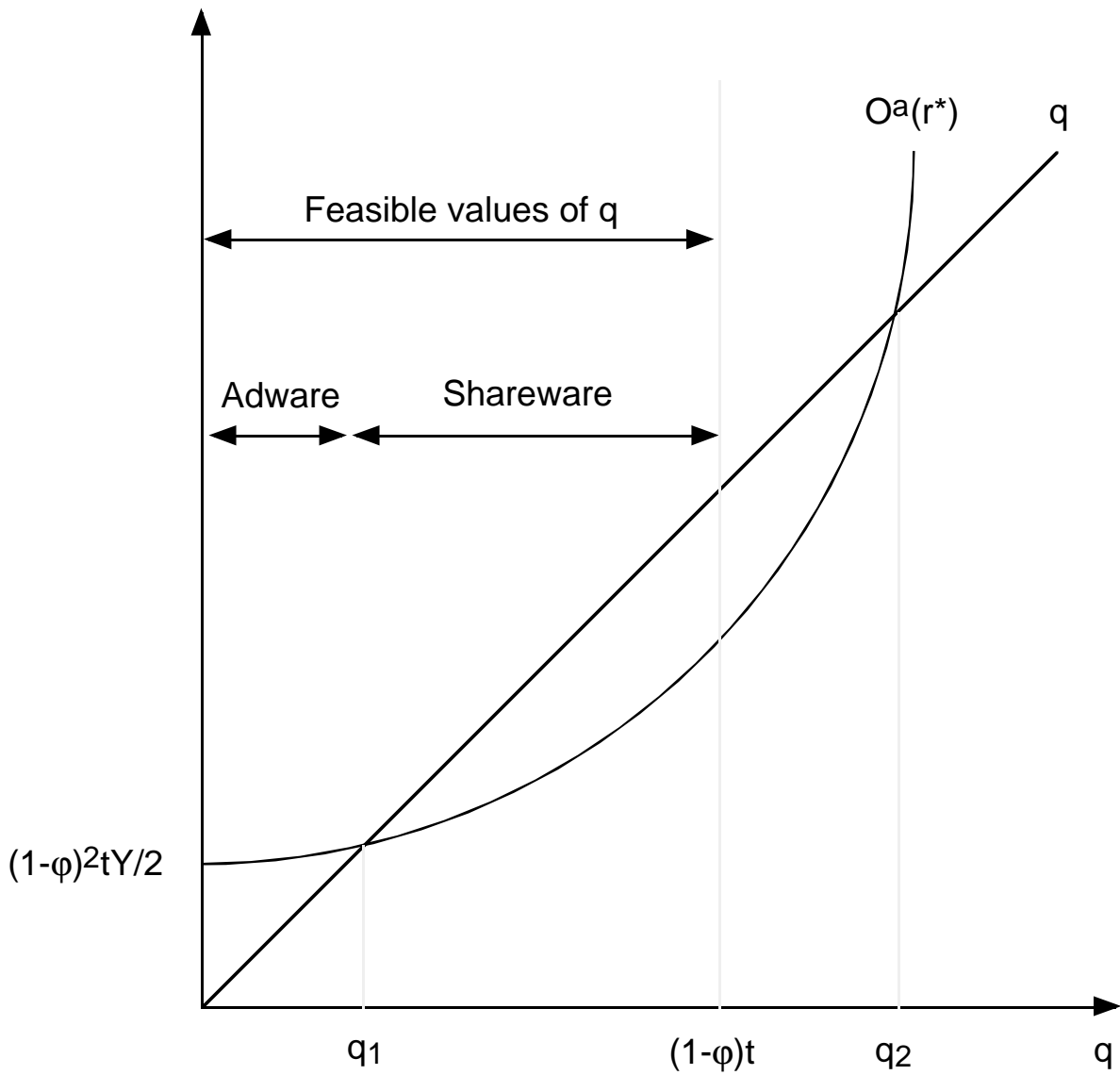


Figure 1: Illustrating the Proposition 1

By continuity, the same is true for small values of  $q$ . But as  $q$  increases, this preference may eventually be reversed provided that  $B \geq -\frac{(1-\varphi)\pi}{z}$ . If  $B < -\frac{(1-\varphi)\pi}{z}$ , the profit from adware exceeds the profit from shareware for feasible values of  $q$  (by Assumption 1,  $q \leq (1-\varphi)t$ ). The reason why the profit from shareware may exceed the profit from adware when  $q$  is large is that the profit from shareware increases one-to-one with  $q$ . By contrast, an increase in  $q$  affects the profit from adware only indirectly by inducing more consumers to adopt adware. The rate of increase in  $O^a(q, r^*)$  is less than 1 for low values of  $q$ .

Casual observation suggests that many popular software are first distributed as adware, but then, newer and improved versions are distributed as shareware. Examples for this pattern include Gozilla and GetRight which are the second and the third most popular download managers on download.com with over 17 million and 11 million downloads respectively. Proposition 1 provides a possible explanation for this pattern. It should be noted that  $q$  need not represent the “true” quality of the software but rather its perceived quality by potential users. If potential users believe that  $q$  is lower than it really is and the programmer has no way of credibly convincing them otherwise, then it pays the programmer to first distribute the software as an adware. As more consumers use the software and learn its true quality, the perceived quality of the software increases and the programmer benefits from distributing newer versions as shareware.

## 4 Comparative statics and policy implications

As we already mentioned in the Introduction, adware technology is still relatively new. It is therefore expected that in the near future, the technology of sending context-based targeted ads to specific consumers through ad banners will improve. For instance, Google plans to offer Gmail which is a free webmail service that will analyze the contents of emails and will place relevant text ads and links to related web pages adjacent to email messages. Such improvement have raised concerns about the increasing loss of privacy on the Internet. It is therefore interesting to find out how such improvements will affect consumers in the context of our model where both privacy loss and the benefits from improved information on consumers’ products are explicitly taken into account. We begin this section by studying this issue. To this end, we assume that an

improvement in the technology of ad banners raises the value of  $z$  towards 0 and enables firms to attract the attention of prospective consumers more effectively. We are interested in finding how the equilibrium outcome and especially consumers' surplus respond to such an increase in  $z$ . Throughout this section we will maintain Assumption 2; that is we assume that  $B \geq \bar{B}$ .

To study the effect of an increase in  $z$ , note from the first lines in equations (14) and (16) that both  $r^*$  and  $O^a(r^*)$  increase with  $z$ . The reason for this is that the demand of firms for ad banners increases which in turn enables the programmer to charge higher prices for ad banners and make more money by distributing the software as adware. Consequently, the programmer offers adware instead of shareware for a wider set of parameters.

Does an increase in  $z$  benefits consumers as well? To address this question, recall that consumers adopt an adware if and only if  $\beta \leq \hat{\beta}(q, \hat{\mu}(r))$ ; the utility of each adware user in group  $i$  is  $U_i^a(\beta)$  while the utility of each non user is  $\bar{U}$ . Recalling that there are  $\frac{1}{n}$  consumers in each group and using equations (5) and (10), consumers' surplus is given by

$$\begin{aligned} CS(q, r) &= \sum_{i=1}^n \frac{1}{n} \int_0^{\hat{\beta}(q, \hat{\mu}(r))} \frac{U_i^a(\beta)}{B} d\beta + \int_{\hat{\beta}(q, \hat{\mu}(r))}^B \frac{\bar{U}}{B} d\beta \\ &= \frac{(q + \hat{\mu}(r)(1 - \varphi)t)^2}{2zB \ln(1 - \hat{\mu}(r))} + \bar{U}. \end{aligned} \quad (17)$$

Substituting for  $r^*$  from the first line of equation (14), the value of consumers' surplus in equilibrium is

$$CS(q, r^*) = \frac{(q + (1 - \varphi)t)^2}{8zB \ln\left(\frac{q + (1 - \varphi)t}{2(1 - \varphi)t}\right)} + \bar{U}.$$

By Assumption 1,  $\ln\left(\frac{q + (1 - \varphi)t}{2(1 - \varphi)t}\right) \leq 0$  implying that  $CS(q, r^*)$  is increasing with  $z$ . Hence, consumers are made better off by a technological improvement in the effectiveness of ad banners. The reason for this is as follows. While consumers can download adware for free, each consumer will get an adware if and only if the benefit from improved information about consumers products exceeds the disutility from privacy loss. Since the utility of consumers who do not adopt an adware,  $\bar{U}$ , is independent of  $z$ , it follows by revealed preferences that an increase in  $z$  boosts consumers' surplus if and only if it increases the fraction of adware users. The latter is given by

$\frac{\bar{B}}{B}$ , which by equation (15) is increasing with  $z$ .

Intuitively, an increase in  $z$  has two effects on consumers. First, holding  $\hat{\mu}(r)$  fixed, an increase in  $z$  means that fewer impressions are needed to get the same level of attention from adware users. Hence, adware leads to a smaller loss of privacy and hence becomes more attractive. Second, an increase in  $z$  affects  $\hat{\mu}(r)$  (the intensity with which firms use ad banners) both directly, as well as indirectly through its effect on  $r^*$ . The direct effect of  $z$  on  $\hat{\mu}(r)$  is positive because an increase in  $z$  makes ad banners more effective in attracting consumers and this boosts the firms' demand for ad banners. At the same time, an increase in  $z$  induces the programmer to raise  $r^*$  and this depresses the firms' demand for ad banners. In our model however, the direct and indirect effects cancel each other out so  $\hat{\mu}(r^*)$  is independent of  $z$ . Consequently, only the first, positive, effect is at work, implying that an increase in  $z$  makes adware more attractive to consumers and hence more consumers adopt the adware.

It should also be noted that since  $\hat{\mu}(r^*)$  is independent of  $z$ , the number of impressions that each adware user gets,  $z \ln(1 - \hat{\mu}(r^*))$ , is decreasing with  $z$ . This implies in turn that an improvement in the ad banners technology will lead to less violation of privacy rather than more as some technological experts expect.

We summarize this discussion in the following proposition:

**Proposition 2:** *An improvement in the ad banners technology that increases  $z$  induces the programmer to adopt adware for a larger set of parameters and to raise the price of ad banners. In equilibrium, more consumers adopt the adware and both the programmer and consumers become better off. Moreover, following the improvement, fewer impression are sent and hence, adware users face smaller loss of privacy.*

We proceed by evaluating the policy implications of Proposition 1. To this end, we first need to characterize the socially efficient outcome. As before, we shall impose Assumption 2 and restrict attention to cases in which  $B \geq \bar{B}$ . Our measure of social welfare is the sum of the consumers' surplus plus profits, which in our context consist of the profits of firms and the programmer's profit.

In the shareware case, all consumers buy the shareware at a price  $p^s = q$ . Hence, by equation (2), consumers' surplus equals  $\bar{U}$ . Noting that the programmer's profit is  $p^s = q$ , and

the aggregate profits of firms are equal to  $\pi$ , social welfare in the shareware's case is

$$W^s(q) = \bar{U} + \pi + q. \quad (18)$$

In the adware case, consumers' surplus is given by equation (17), while the aggregate profits of firms are  $\sum_{i=1}^n \Pi_i(\hat{\mu}(r), \dots, \hat{\mu}(r))$ , and the programmer's profit  $rz \sum_{i=1}^n \frac{\alpha}{n} \ln(1 - \hat{\mu}(r))$ , where  $\alpha = \frac{\hat{\beta}(q, \hat{\mu}(r))}{B}$  is the fraction of adware users. Since the payments of firms to the programmer are washed out, the sum of the aggregate profits of firms and the programmer's profit equal  $\pi$ . Hence, social welfare in the adware's case is

$$W^a(q, r) = \bar{U} + \pi + \frac{(q + \hat{\mu}(r)(1 - \varphi)t)^2}{2zB \ln(1 - \hat{\mu}(r))}. \quad (19)$$

The socially optimal value of  $r$ , denoted  $r^{**}$ , maximizes  $W^a(q, r)$ . In the following result we compare  $r^{**}$  with the equilibrium value of  $r$ ,  $r^*$ , which is given in the first line of equation (14):

**Proposition 3:** *The equilibrium value of  $r$  is excessive:  $r^* > r^{**}$  for all values of  $q$  for which the programmer offers an adware. Consequently, in equilibrium, there is too few ad banners.*

**Proof:** The socially optimal per-viewer price of ad banners,  $r^{**}$ , is implicitly defined by the following first order condition:

$$\frac{\partial W^a(q, r)}{\partial r} = 2 \left( \frac{(1 - \hat{\mu}(r)) \ln(1 - \hat{\mu}(r)) (1 - \varphi)t}{q + \hat{\mu}(r)(1 - \varphi)t} + \frac{1}{2} \right) \frac{CS(q, r) \hat{\mu}'(r)}{(1 - \hat{\mu}(r)) \ln(1 - \hat{\mu}(r))} = 0. \quad (20)$$

Noting that  $\ln(1 - \hat{\mu}(r)) \leq 0$  and recalling from equation (8) that  $\hat{\mu}'(r) < 0$ , the sign of  $\frac{\partial W^a(q, r)}{\partial r}$  depends on the sign of the bracketed term in equation (20). Evaluating this term at  $r^*$  and recalling that  $\hat{\mu}(r^*) = \frac{(1 - \varphi)t - q}{2(1 - \varphi)t}$  whenever  $B \geq \bar{B}$ , yields

$$\text{sign} \left( \frac{\partial W^a(q, r^*)}{\partial r} \right) = \text{sign} \left( \ln \left( \frac{q + (1 - \varphi)t}{2(1 - \varphi)t} \right) + \frac{1}{2} \right),$$

where  $\ln \left( \frac{q + (1 - \varphi)t}{2(1 - \varphi)t} \right) + \frac{1}{2} < 0$  for all  $q \leq (1 - \varphi)t \left( \frac{2}{\sqrt{e}} - 1 \right)$ . Hence,  $r^* > r^{**}$  for all  $q \leq (1 - \varphi)t \left( \frac{2}{\sqrt{e}} - 1 \right)$ . Now, recall from Proposition 1 that the programmer offers an adware if

and only if  $q \leq q_1$  and note that

$$\begin{aligned}
& (1 - \varphi) t \left( \frac{2}{\sqrt{e}} - 1 \right) - q_1 \\
&= \frac{t}{-\frac{\pi}{2zB}} \left[ \sqrt{1 + \frac{(1 - \varphi)\pi}{zB}} - \left( 1 + \frac{(1 - \varphi)\pi}{\sqrt{e}zB} \right) \right] \\
&> \frac{t}{-\frac{\pi}{2zB}} \left[ 1 + \frac{(1 - \varphi)\pi}{zB} - \left( 1 + \frac{(1 - \varphi)\pi}{\sqrt{e}zB} \right) \right] \\
&= \frac{t}{-\frac{\pi}{2zB}} \left[ \frac{(1 - \varphi)\pi}{zB} - \frac{(1 - \varphi)\pi}{\sqrt{e}zB} \right] > 0,
\end{aligned}$$

where the first inequality follows because  $z < 0$ . Hence,  $q_1 < (1 - \varphi) t \left( \frac{2}{\sqrt{e}} - 1 \right)$ . This implies in turn that for values of  $q$  for which the programmer offers adware,  $r^* > r^{**}$ . The conclusion regarding ad banners follows by noting that  $\hat{\mu}'(r) < 0$ . ■

Proposition 3 indicates that whenever the programmer offers adware, the equilibrium price of ad banners,  $r$ , is excessive; as a result, there is too little usage of ad banners by firms.<sup>10</sup> Intuitively, when the programmer sets  $r$ , he fails to take into account the resulting effect on adware users. Given that an increase in  $r$  induces firms to buy fewer ad banners, it is clear that  $r$  will end up being excessive if on average, the benefit of adware users from information on consumers' products exceeds their disutility from privacy loss. For adware users with low values of  $\beta$ , the benefit clearly exceeds the cost. For adware users with high values of  $\beta$ , the cost exceeds the benefit since adware users also get a utility  $q$  from using the software itself and hence are willing to adopt the adware even when their disutility from privacy loss exceeds the benefit from information about consumers' products. As  $q$  increases, there are more adware users for whom the net effect of ad banners is negative. But since the programmer switches to shareware when  $q$  increases above  $q_1$ , the fraction of adware users for whom the effect of ad banners is negative must be limited. Proposition 3 shows that, indeed, so long as the programmers offers an adware, the aggregate benefit of consumers from ad banners exceeds the associated disutility. The programmer fails to take into account this net benefit and hence sets an excessive price for ad banners.

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<sup>10</sup>Again, it is worth emphasizing that we only consider "legitimate" ad-supported software, but not spyware and malware, which, from personal experience, are a major nuisance.

Proposition 3 compares the equilibrium value of  $r$  with its socially optimal value. However, this comparison is relevant only if the programmer distributes his software as an adware. Our next task is to compare the equilibrium choice between adware and shareware with the socially optimal choice.

**Proposition 4:** *The programmer offers an adware for a smaller set of parameters than is socially efficient whenever  $r^* z \ln(1 - \hat{\mu}(r^*)) \leq \frac{1}{2}$  and offers an adware for a wider set of parameters than is socially efficient whenever  $r^{**} z \ln(1 - \hat{\mu}(r^{**})) \geq \frac{1}{2}$ .*

**Proof:** It is socially efficient to distribute the software as an adware if and only if  $W^a(q, r^{**}) \geq W^s(q)$ . Using equations (18) and (19), this condition is equivalent to

$$\frac{(q + \hat{\mu}(r^{**})(1 - \varphi)t)^2}{2zB \ln(1 - \hat{\mu}(r^{**}))} \geq q. \quad (21)$$

Using the first line in equation (16), it follows that in equilibrium, the programmer will distribute his software as an adware if and only if

$$\frac{(q + \hat{\mu}(r^*)(1 - \varphi)t)^2 r^*}{B} \geq q. \quad (22)$$

Hence, to prove the proposition it is sufficient to prove that the left side of (21) exceeds the left side of (22). Now, suppose that  $r^* z \ln(1 - \hat{\mu}(r^*)) \leq \frac{1}{2}$ . Then,

$$\begin{aligned} \frac{(q + \hat{\mu}(r^{**})(1 - \varphi)t)^2}{2zB \ln(1 - \hat{\mu}(r^{**}))} &\geq \frac{(q + \hat{\mu}(r^*)(1 - \varphi)t)^2}{2zB \ln(1 - \hat{\mu}(r^*))} \\ &\geq \frac{(q + \hat{\mu}(r^*)(1 - \varphi)t)^2 r^*}{B}, \end{aligned}$$

where the first inequality follows by revealed preferences ( $r^{**}$  maximizes the left side of (21)).

On the other hand, if  $r^{**} z \ln(1 - \hat{\mu}(r^{**})) \geq \frac{1}{2}$ , then,

$$\begin{aligned} \frac{(q + \hat{\mu}(r^*)(1 - \varphi)t)^2 r^*}{B} &\geq \frac{(q + \hat{\mu}(r^{**})(1 - \varphi)t)^2 r^{**}}{B} \\ &\geq \frac{(q + \hat{\mu}(r^{**})(1 - \varphi)t)^2}{2zB \ln(1 - \hat{\mu}(r^{**}))}, \end{aligned}$$

where the first inequality follows by revealed preferences ( $r^*$  maximizes the left side of (22)).

■

To interpret Proposition 4, note from the second line of (12) that  $z \ln(1 - \hat{\mu}(r))$  is the aggregate demand for ad banners when all consumers adopt the adware. Hence,  $rz \ln(1 - \hat{\mu}(r))$  is the programmer's profit when the adware market is covered. Proposition 4 states that the programmer will underprovide adware if, evaluated at the profit maximizing price of ad banners,  $r^*$ , this profit is sufficiently small, but will overprovide adware if at the socially optimal price of ad banners,  $r^{**}$ , this profit is sufficiently large. To go deeper into the sufficient conditions in Proposition 4, note that

$$r^* z \ln(1 - \hat{\mu}(r^*)) = -\frac{(q + (1 - \varphi)t)\pi}{2t} \ln\left(\frac{q + (1 - \varphi)t}{2(1 - \varphi)t}\right).$$

By Assumption 1,  $\ln\left(\frac{q + (1 - \varphi)t}{2(1 - \varphi)t}\right) \leq 0$ , so this expression increases with  $\pi$ . Hence, underprovision of adware is especially likely when the profit of firms on consumers' products,  $\pi$ , is small. By contrast,

$$r^{**} z \ln(1 - \hat{\mu}(r^{**})) = r^{**} z \ln\left(1 - \frac{r^{**} z}{(1 - \varphi)\pi}\right),$$

where (20) shows that  $r^{**}$  is independent of  $\pi$ . Hence,  $r^{**} z \ln(1 - \hat{\mu}(r^{**}))$  is decreasing with  $\pi$ , implying that the sufficient condition for overprovision of adware is especially likely to hold when  $\pi$  is large.

As we mentioned in the Introduction, currently, U.S. legislators are considering legislation that would regulate or even completely ban any software that monitors usage of the internet and transmits information back from a location. Such legislation is mainly motivated by the rapid growth of spyware and malware. However, the legislation may also effectively make it impossible to distribute legitimate adware on line. Using our model we can examine the desirability of bans on adware.

**Proposition 5:** *A ban on adware hurts both consumers and the programmer when  $q \leq q_1$  and is irrelevant otherwise.*

**Proof:** When  $q > q_1$ , the programmer offers shareware so a ban on adware is irrelevant. When  $q \leq q_1$ , the programmer prefers to offer adware. By revealed preferences, it is obvious that a ban on adware would hurt the programmer in this range. As for consumers, note that consumers' surplus is  $\bar{U}$  in the shareware case and  $CS(q, r^*)$  in the adware case. The difference between the two expressions is

$$\bar{U} - CS(q, r^*) = -\frac{(q + (1 - \varphi)t)^2}{8zB \ln\left(\frac{q + (1 - \varphi)t}{2(1 - \varphi)t}\right)} < 0.$$

Hence, a ban on adware hurts consumers as well. ■

That a ban on adware hurts the programmer is obvious. Less obvious is why such a ban hurts consumers. The reason for this is simple however: when the programmer offers shareware, he charges consumers a price equal to their benefit from using the software. Hence, consumers get no surplus from the shareware. On the other hand, when the programmer offers adware, consumers with low privacy concerns get a positive surplus from the adware while those with high privacy concerns do not adopt it. Hence, a ban on adware hurts consumers.

## 5 Competition in the software market

In this section we consider competition between two programmers who develop software of equal quality. Given that the quality of the software is the same, it is clear that in order to avoid Bertrand competition, one programmer will choose to distribute his software as shareware and the other will choose to distribute it as adware. In what follows, we study the ensuing competition between the two programmers by solving the following three stage game. In the first stage, the two programmers simultaneously choose their prices: the shareware programmer chooses the price of shareware,  $p^s$ , while adware programmer chooses the per-impression price,  $r$ . Given  $r$ , firms decide in the second stage of the game how many ad banners to pay for. In the third stage, each consumer decides whether to get a shareware or an adware. Finally, consumers buy products and all payoffs are realized.

The profit of the shareware programmer is

$$(1 - \alpha)p^s,$$

where  $1 - \alpha$  is the fraction of consumers who decide to purchase shareware. The profit of the adware programmer is

$$rz \sum_{i=1}^n \ln(1 - \mu_i).$$

Given  $r$ , the intensity of advertising through ad banners,  $\hat{\mu}(r)$ , is given by equation (8), just as in the single programmer's case. Notice that each firm  $i$ 's decision about  $\mu_i$  is independent of the number of consumers who will eventually get an adware. Hence, we can solve for the second stage of the game independently of the third stage. The equilibrium prices will be denoted by  $\hat{p}^s$  and  $\hat{r}$ .

## 5.1 Shareware vs. adware

Consumers decide whether to get adware or shareware by comparing their utilities from the two options. Using equations (2) and (5), and noting that  $\mu_i = \hat{\mu}(r)$  for all  $i$ , it follows that consumers will choose to get adware if

$$U_i^a(\beta) - U^s = p^s - \beta z \ln(1 - \hat{\mu}(r)) + \hat{\mu}(r)(1 - \varphi)t \geq 0,$$

and will choose to get shareware otherwise. Since  $\ln(1 - \hat{\mu}(r)) \leq 0$  and  $z < 0$ , this expression is decreasing with  $\beta$ . Hence, the equation  $U^a(\beta) = U^s$  defines a unique value of  $\beta$ , denoted  $\hat{\beta}(p^s, \hat{\mu}(r))$ , below which the consumer will choose to get an adware and above which he will choose to get a shareware:

$$\hat{\beta}(p^s, \hat{\mu}(r)) = \frac{p^s + \hat{\mu}(r)(1 - \varphi)t}{z \ln(1 - \hat{\mu}(r))}. \quad (23)$$

That is, consumers with small privacy concerns will purchase adware while those with large concerns will purchase shareware. Notice that  $\hat{\beta}(p^s, \hat{\mu}(r))$  is an increasing function of  $p^s$ : the

higher the price of shareware, the more consumers will adopt a adware rather than shareware. In other words, adware and shareware are substitutes for consumers.

In order to avoid corner solutions, we shall make the following assumption:

**Assumption 3:**  $B > \widehat{\beta}(\widehat{p}^s, \widehat{\mu}(\widehat{r}))$ .

Assumption 3 modifies Assumption 2 by setting a new lower bound on  $B$ . This assumption ensures that  $B$  is sufficiently large to ensure that in equilibrium, at least some consumers will find the disutility from privacy loss so large that they will prefer to adopt shareware instead of adware. Of course, the shareware programmer can always lower  $p^s$  to induce some consumers to adopt shareware. Assumption 3 ensures that if  $p^s$  is lowered to 0, the shareware programmer can attract at least some consumers.

Since  $\beta$  is uniformly distributed in the population on the interval  $[0, B]$ , the fraction of consumers who adopt an adware is

$$\widehat{\alpha}(p^s, r) = \frac{\widehat{\beta}(p^s, \widehat{\mu}(r))}{B}. \quad (24)$$

Given  $\widehat{\alpha}(p^s, r)$ , the demand for shareware is  $1 - \widehat{\alpha}(p^s, r)$ , so the profit of the shareware programmer is

$$O^s(p^s, r) = (1 - \widehat{\alpha}(p^s, r)) p^s = \left(1 - \frac{p^s + \widehat{\mu}(r)(1 - \varphi)t}{zB \ln(1 - \widehat{\mu}(r))}\right) p^s, \quad (25)$$

where  $\widehat{\mu}(r)$  is given by equation (8). The profit of the adware programmer is

$$O^a(p^s, r) = \widehat{\alpha}(p^s, r) z \ln(1 - \widehat{\mu}(r)) r = \frac{(p^s + \widehat{\mu}(r)(1 - \varphi)t) r}{B}. \quad (26)$$

## 5.2 Shareware prices and per-impression prices

In the first stage of the game, the shareware programmer chooses the price of shareware,  $p^s$ , while adware programmer chooses the per-impression price,  $r$ .

**Lemma 1:** *There exists a unique Nash equilibrium,  $(\widehat{p}^s, \widehat{r})$ , where  $\widehat{p}^s > 0$  and  $-\frac{(1-\varphi)\pi}{3z} < \widehat{r} < -\frac{(1-\varphi)\pi}{2z}$ .*

**Proof:** It is straightforward to verify that  $\frac{\partial^2 O^s(p^s, r)}{\partial (p^s)^2} = -\frac{2}{zB \ln(1-\hat{\mu}(r))} < 0$  and  $\frac{\partial^2 O^a(p^s, r)}{\partial r^2} = -\frac{2}{z\pi} < 0$ . Hence, the best response functions of the shareware and adware programmers, respectively, are uniquely defined by the first order conditions,  $\frac{\partial O^s(p^s, r)}{\partial p^s} = 0$  and  $\frac{\partial O^a(p^s, r)}{\partial r} = 0$ . Using equation (8) and simplifying, the best response functions of the two programmers are given by:

$$BR^s(r) = \frac{zB \ln\left(\frac{-rz}{(1-\varphi)\pi}\right) - (1-\varphi)t - \frac{rzt}{\pi}}{2}, \quad (27)$$

and

$$BR^a(p^s) = -\frac{(p^s + (1-\varphi)t)\pi}{2zt}. \quad (28)$$

To prove the existence of a Nash equilibrium, we must prove that (27) and (28) intersect in the  $(\hat{p}^s, \hat{r})$  space. Substituting for  $p^s = BR^s(r)$  from (27) into (28) yields

$$\frac{3rt}{\pi} + B \ln\left(\frac{-rz}{(1-\varphi)\pi}\right) = \frac{(1-\varphi)t}{-z}. \quad (29)$$

The left hand side of (29) increases with  $r$ , while the right hand side is independent of  $r$ . Moreover, as  $r$  goes to 0, the left hand side of (29) goes to  $-\infty$  while as  $r$  goes to  $\infty$ , the hand side of the right hand side of (29) goes to  $\infty$ . Hence, equation (29) has a unique solution that we denote by  $\hat{r}$ .

By (28), it follows that in equilibrium,

$$\hat{p}^s = -\frac{2\hat{r}zt}{\pi} - (1-\varphi)t. \quad (30)$$

Since  $\hat{r}$  is unique, so is  $\hat{p}^s$ . Moreover, substituting for  $\ln\left(\frac{-rz}{(1-\varphi)\pi}\right)$  from (29) into  $\hat{\beta}(\hat{p}^s, \hat{\mu}(\hat{r}))$  and simplifying terms, reveals that Assumption 3 ensures that  $-\frac{2\hat{r}zt}{\pi} - (1-\varphi)t > 0$ . Hence, (30) implies that  $\hat{p}^s > 0$ .

Finally,  $-\frac{2\hat{r}zt}{\pi} - (1-\varphi)t > 0$  implies that

$$\hat{r} < -\frac{(1-\varphi)\pi}{2z}.$$

On the other hand, since  $\ln\left(\frac{-\widehat{r}z}{(1-\varphi)\pi}\right) < 0$ , (29) implies that  $\frac{3\widehat{r}}{\pi} + \frac{(1-\varphi)}{z} > 0$ , or

$$\widehat{r} > -\frac{(1-\varphi)\pi}{3z}.$$

■

Next we examine how an improvement in the ad banners' technology that increases  $z$  towards 0 affects the equilibrium prices, profits, and consumers' surplus.

**Proposition 6:** *An increase in  $z$  leads to an increase in  $\widehat{r}$  and a decrease in  $\widehat{p}^s$ . Moreover,  $O^s(\widehat{p}^s, \widehat{r})$  decreases while  $O^a(\widehat{p}^s, \widehat{r})$  and consumers' surplus increase.*

**Proof:**  $\widehat{r}$  is defined implicitly by (29). Differentiating this equation with respect to  $\widehat{r}$  and  $z$  and rearranging terms,

$$\frac{\partial \widehat{r}}{\partial z} = \frac{(1-\varphi)t - zB}{z^2 \left(\frac{3t}{\pi} + \frac{B}{\widehat{r}}\right)} > 0. \quad (31)$$

Differentiating (30) with respect to  $\widehat{p}^s$  and  $z$ , using (31), and rearranging terms,

$$\begin{aligned} \frac{\partial \widehat{p}^s}{\partial z} &= -\frac{2t}{\pi} \left( \widehat{r} + z \frac{\partial \widehat{r}}{\partial z} \right) \\ &= -\frac{2t}{\pi} \left( \frac{\frac{3\widehat{r}t}{\pi} + \frac{(1-\varphi)t}{z}}{\frac{3t}{\pi} + \frac{B}{\widehat{r}}} \right) < 0, \end{aligned} \quad (32)$$

where the last equality follows because by (29),  $\frac{3\widehat{r}t}{\pi} + \frac{(1-\varphi)t}{z} = -B \ln\left(\frac{-\widehat{r}z}{(1-\varphi)\pi}\right) > 0$ .

Differentiating (26) with respect to  $z$ , using the envelope theorem, and substituting from (32) for  $\frac{\partial \widehat{p}^s}{\partial z}$ :

$$\begin{aligned} \frac{\partial O^a(\widehat{p}^s, \widehat{r})}{\partial z} &= \frac{\widehat{r}^2 t}{\pi B} + \frac{\widehat{r}}{B} \frac{\partial \widehat{p}^s}{\partial z} \\ &= \frac{\widehat{r}t}{\pi B \left(\frac{3t}{\pi} + \frac{B}{\widehat{r}}\right)} \left[ B - \frac{3\widehat{r}t}{\pi} - \frac{2(1-\varphi)t}{z} \right] \\ &> \frac{\widehat{r}t}{\pi B \left(\frac{3t}{\pi} + \frac{B}{\widehat{r}}\right)} \left[ B - \frac{(1-\varphi)t}{2z} \right] > 0, \end{aligned}$$

where the first inequality follows because by Lemma 1,  $\hat{r} < -\frac{(1-\varphi)\pi}{2z}$ , and the second inequality follows because  $z < 0$ .

Differentiating (25) with respect to  $z$ , using the envelope theorem, substituting for  $\hat{p}^s$  from (30), and rearranging,

$$\frac{\partial O^s(\hat{p}^s, \hat{r})}{\partial z} = -\frac{\frac{t}{\pi} \left( (2\hat{r} + z\frac{\partial \hat{r}}{\partial z}) \ln \left( \frac{-\hat{r}z}{(1-\varphi)\pi} \right) + \hat{r} + z\frac{\partial \hat{r}}{\partial z} \right) \hat{p}^s}{zB \left( \ln \left( \frac{-\hat{r}z}{(1-\varphi)\pi} \right) \right)^2}.$$

Since  $z < 0$ ,

$$\text{sign} \left( \frac{\partial O^s(\hat{p}^s, \hat{r})}{\partial z} \right) = \text{sign} \left( \left( 2\hat{r} + z\frac{\partial \hat{r}}{\partial z} \right) \ln \left( \frac{-\hat{r}z}{(1-\varphi)\pi} \right) + \hat{r} + z\frac{\partial \hat{r}}{\partial z} \right).$$

Substituting for  $\ln \left( \frac{-\hat{r}z}{(1-\varphi)\pi} \right)$  from (29) and for  $\frac{\partial \hat{r}}{\partial z}$  from (31) and rearranging terms,

$$\begin{aligned} \text{sign} \left( \frac{\partial O^s(\hat{p}^s, \hat{r})}{\partial z} \right) &= \text{sign} \left[ \left( 2\hat{r} + \frac{(1-\varphi)t - zB}{z \left( \frac{3t}{\pi} + \frac{B}{\hat{r}} \right)} \right) \left( -\frac{3\hat{r}t}{\pi B} - \frac{(1-\varphi)t}{zB} \right) + \hat{r} + \frac{(1-\varphi)t - zB}{z \left( \frac{3t}{\pi} + \frac{B}{\hat{r}} \right)} \right] \\ &= \text{sign} \left[ -\frac{6\hat{r}t}{\pi} + \frac{(1-\varphi)t}{z} \left( \frac{3\hat{r}t}{\pi} + \frac{(1-\varphi)t}{z} \right) \right]. \end{aligned}$$

The proof is completed by noting that the bracketed expression is negative since equation (29) implies that  $\frac{3\hat{r}t}{\pi} + \frac{(1-\varphi)t}{z} = -B \ln \left( \frac{-rz}{(1-\varphi)\pi} \right) > 0$  and  $\frac{6\hat{r}t}{\pi} + \frac{(1-\varphi)t}{z} = \frac{3\hat{r}t}{\pi} - B \ln \left( \frac{-rz}{(1-\varphi)\pi} \right) > 0$ .

To examine the effect of  $z$  on consumers, recall that consumers get an adware if  $\beta \leq \hat{\beta}(\hat{p}^s, \hat{\mu}(\hat{r}))$  and shareware if  $\beta > \hat{\beta}(\hat{p}^s, \hat{\mu}(\hat{r}))$ . The utility of each adware user in group  $i$  is  $U_i^a(\beta)$  while the utility of each shareware user is  $U^s$ . Using equations (2), (5), (23), (8), and (30), it follows that consumers' surplus is given by

$$\begin{aligned} CS(\hat{p}^s, \hat{r}) &= \sum_{i=1}^n \frac{1}{n} \int_0^{\hat{\beta}(\hat{p}^s, \hat{\mu}(\hat{r}))} \frac{U_i^a(\beta)}{B} d\beta + \int_{\hat{\beta}(\hat{p}^s, \hat{\mu}(\hat{r}))}^B \frac{U^s}{B} d\beta \quad (33) \\ &= \frac{(\hat{p}^s + \hat{\mu}(\hat{r})(1-\varphi)t)^2}{2zB \ln(1 - \hat{\mu}(\hat{r}))} + q - \hat{p}^s + \bar{U} \\ &= \frac{\hat{r}^2 z t^2}{2\pi^2 B \ln \left( \frac{-\hat{r}z}{(1-\varphi)\pi} \right)} + q - \hat{p}^s + \bar{U}. \end{aligned}$$

Differentiating (33) with respect to  $z$ ,

$$\frac{\partial CS(\widehat{p}^s, \widehat{r})}{\partial z} = \frac{\widehat{r}t^2}{2\pi^2 B \ln\left(\frac{-\widehat{r}z}{(1-\varphi)\pi}\right)^2} \left[ \ln\left(\frac{-\widehat{r}z}{(1-\varphi)\pi}\right) \left(\widehat{r} + 2z \frac{\partial \widehat{r}}{\partial z}\right) - \left(\widehat{r} + z \frac{\partial \widehat{r}}{\partial z}\right) \right] - \frac{\partial \widehat{p}^s}{\partial z}.$$

Substituting for  $\ln\left(\frac{-\widehat{r}z}{(1-\varphi)\pi}\right)$  from (29) and for  $\frac{\partial \widehat{r}}{\partial z}$  from (31) and rearranging terms

$$\frac{\partial CS(\widehat{p}^s, \widehat{r})}{\partial z} = \frac{\widehat{r}t^2 G(\widehat{r})}{2\pi^3 z^2 \left(\frac{3\widehat{r}t}{\pi} + B\right) \left(\frac{3\widehat{r}}{\pi} + \frac{(1-\varphi)}{z}\right)},$$

where

$$G(\widehat{r}) \equiv 4(1-\varphi)^2 \pi^2 + 22(1-\varphi)\pi \widehat{r}z + 33\widehat{r}^2 z^2.$$

The denominator in  $\frac{\partial CS(\widehat{p}^s, \widehat{r})}{\partial z}$  is positive since equation (29) implies that  $\frac{3\widehat{r}}{\pi} + \frac{(1-\varphi)}{z} = -\frac{B}{t} \ln\left(\frac{-rz}{(1-\varphi)\pi}\right) > 0$ . To determine the sign of  $G(\widehat{r})$ , note that  $G(\widehat{r})$  is convex function of  $\widehat{r}$  and attains a unique minimum point at  $\widehat{r} = \frac{(1-\varphi)^2 \pi^2}{3}$ . Since  $G\left(\frac{(1-\varphi)^2 \pi^2}{3}\right) = 66z^2 > 0$ , it follows that the  $G(\widehat{r}) > 0$  for all  $\widehat{r}$ . Hence,  $\frac{\partial CS(\widehat{p}^s, \widehat{r})}{\partial z} > 0$ . ■

Proposition 6 shows that the conclusions from Section 4 about the impact of an improvement in the technology of ad banners carry over to the case where there is competition in the software market. In particular, the technological improvement benefits the adware programmer as well as consumers. Proposition 6 shows that the improvement lowers the price of shareware and hurts the shareware programmer.

Finally, we reexamine the effect of a ban on the distribution of adware on the programmers and on consumers when there is competition in the software market.

**Proposition 7:** *A ban on adware hurts both consumers and the programmers.*

**Proof:** A ban on adware induces both programmers to distribute their software as shareware. Since the software of both programmers is assumed to have the same quality, competition in the software market drives  $p^s$  to 0. Hence, consumers' surplus is  $q + \overline{U}$ . Absent a ban, consumers' surplus is  $CS(\widehat{p}^s, \widehat{r})$ . Substituting for  $\widehat{p}^s$  from (30) and for  $B \ln\left(\frac{-\widehat{r}z}{(1-\varphi)\pi}\right)$  from (29)

and simplifying, the difference between the two expressions is

$$\begin{aligned} q + \bar{U} - CS(\hat{p}^s, \hat{r}) &= \frac{\hat{r}^2 z t^2}{2\pi^2 B \ln\left(\frac{-\hat{r}z}{(1-\varphi)\pi}\right)} - \hat{p}^s \\ &= -\frac{tM(\hat{r})}{2\pi^2 z \left(\frac{3\hat{r}}{\pi} + \frac{(1-\varphi)}{z}\right)}, \end{aligned}$$

where

$$M(\hat{r}) \equiv 11\hat{r}^2 z^2 + 10\hat{r}z(1-\varphi)\pi + 2(1-\varphi)^2 \pi^2.$$

The sign of  $q + \bar{U} - CS(\hat{p}^s, \hat{r})$  depends on the sign of  $M(\hat{r})$  since 29) implies that  $\frac{3\hat{r}}{\pi} + \frac{(1-\varphi)}{z} = -\frac{B}{t} \ln\left(\frac{-\hat{r}z}{(1-\varphi)\pi}\right) > 0$ .  $M(\hat{r})$  is a convex function of  $\hat{r}$  and  $M(\hat{r}) = 0$  has two solutions,  $\hat{r}_1 = -\frac{0.297(1-\varphi)\pi}{z}$  and  $\hat{r}_2 = -\frac{0.612(1-\varphi)\pi}{z}$  such that a ban on adware harms consumers if and only if  $\hat{r}_1 \leq \hat{r} \leq \hat{r}_2$ . Given Lemma 1,  $\hat{r}$  is indeed in this range. ■

Propositions 7 shows that the welfare implications of a ban on adware derived in Section 4 is robust to the introduction of competition in the software market: the ban harms the programmers as well as consumers.

## 6 Conclusion

We have developed a framework for studying the choice of programmers between distributing their software online as shareware and adware. Our model takes explicit account of the strategic interaction between the programmers, advertisers, and consumers and highlights the tradeoff that adware users face between improved information on consumer products and the violation of their privacy. Given this tradeoff, consumers choose to get adware only if their privacy concerns are small. Otherwise, consumers will either not adopt a software, when only adware is available, or will get a shareware when there is competition in the market for software.

Our model reveals that programmers will prefer to distribute their software to consumers for free as adware when its perceived quality is low but will prefer to sell it as shareware when its perceived quality increases. The model also reveals that improvements in the technology of ad

banners will lead to less violation of privacy and will benefit consumers. By contrast, although a ban on adware will protect the privacy of software users, it will also prevent them from getting targeted information about consumer products and will therefore make them worse off

Finally, although our model considers the market for software it can also be applicable to media markets. In this context, our model can be used to study the choice of content providers between selling their content to consumers for a fee or distributing it to consumers for free and supporting it with advertising. With this interpretation in mind, our paper is related to some of the literature on media markets. In particular, Hansen and Kyhl(2001) compare two alternatives for financing the broadcasts of special events on TV (like sport events): pay-per-view and TV commercials. They find that advertising leads to a higher consumers' surplus than pay-per-view. This result is similar to our result that bans on adware (which are akin to bans on advertising in their model) will hurt consumers.

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